NASA Artemis I DOLILU Summary

Karen M. Altino
SLS DOLILU NEMA Team, Lead
NASA/MSFC EV44 Natural Environments Branch

Joan Brewer
JSC DOLILU Team
IMOC II/JSC CM4 Flight Dynamics Trajectory Branch

Spring NE DOLWG
26 April 2023

Agenda

- Background of NASA Artemis Program DOLILU (Day-of-Launch Initialization I-Load Update) Process
- Summary of Artemis I DOLILU Operations
  - Personnel
  - Function
  - Timeline
- Implementation of Eastern Range Live Weather Data
- Lessons Learned & Forward Work
- Summary

NASA Photo
(https://www.nasa.gov/multimedia/imagegallery/index.html.flicker)

DOLILU Background

- The NASA Artemis program requires a DOLILU process to increase launch availability and ensure that vehicle structural loads are acceptable during Ascent.

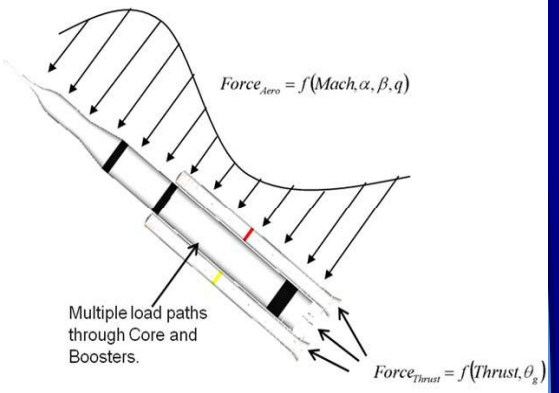
- The DOLILU process is executed in the hours prior to launch.
  - Wind and atmosphere data are measured on day-of-launch (DOL) and used to generate Ascent open-loop guidance steering commands ("I-Loads"= Initialization Loads), which are uploaded to the vehicle
    - Helps to reduce the total angle of attack through the high-q region of Ascent
    - Minimizes aerodynamic loads→ higher probability for launch on a given day

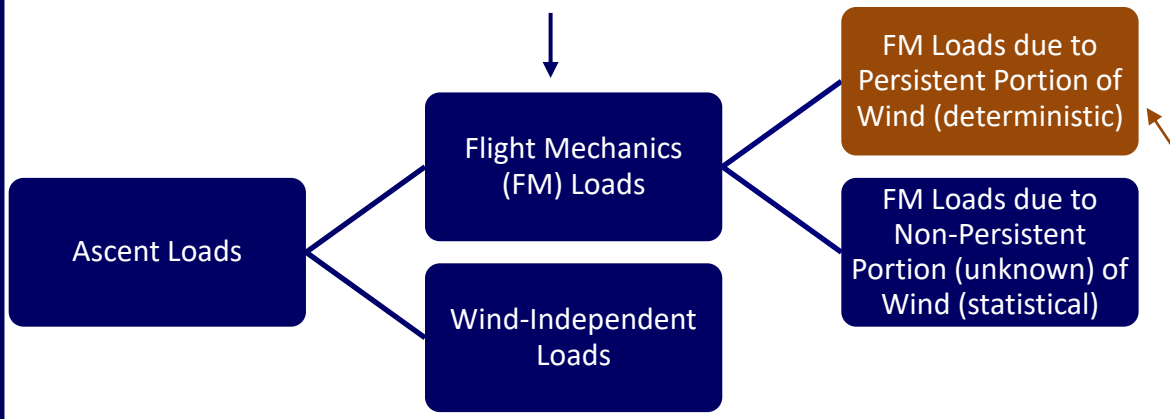
- The new DOLILU system was envisioned and designed in preparation for the Artemis I mission and beyond.
  - A NASA cross-program team worked to develop DOLILU data, software, procedures, and operational processes.
  - Meteorological data provided from the Eastern Range (ER) to Johnson Space Center (JSC) and to Marshall Space Flight Center (MSFC) is through a secure direct connection to an ER data server.
  - The DOLILU system was practiced and tested in a series of development/training simulations leading up to launch.
  - The system was designed with reliability, flexibility, and repeatability in mind for any planned Artemis I launch day opportunities within a given Launch Period (LP).

- The DOLILU process was successfully exercised during the Artemis I launch from ER Launch Pad 39B on 16 Novemberv 2022.

DOLILU Background (cont'd)

- Nonzero aerodynamic angles induce aerodynamic loading and thrust vector control loading (due to steering commands attempting to offset the wind-induced aerodynamic angles).
  This is the wind-driven (flight mechanics) part of the load





Only loads computed on the DOL

- The flight mechanics (wind-induced) loads, due to the persistent portion of the wind, are the only loads being computed on the DOL and are directly based on the trajectory produced from the measured DOL wind.
  - The main benefit of DOL – from a loads perspective – is that this portion of the load can be treated deterministically (no need to statistically cover for ~2000 of these.).
  - These loads are often referred to as the "VLI" (Vehicle Load Indicator) or "STEL" (static aeroelastic) loads.
- Examples of loads due to non-persistent portion of wind:
  - Gust, Lack of Wind Persistence (LoWP)
- Examples of wind-independent loads
  - Buffet, Thrust Oscillation

Artemis I DOLILU Personnel

The DOLILU system involved DOLILU team personnel at JSC and MSFC, as well as other personnel and stakeholders at various locations:

- JSC (Johnson Space Center, Texas) DOLILU Team – Prime DOLILU
- MSFC (Marshall Space Flight Center, Alabama) DOLILU NEMA Team – Natural Environments, SLS IV&V DOLILU
- KSC (Kennedy Space Center, Florida) – Upload I-Loads to SLS Flight Computers
- CCSFS (Cape Canaveral Space Force Station, Florida) – Wx Instrumentation (TDRWP, LR balloon releases)

JSC DOLILU Team Function

Flight Operations Directorate (FOD) DOLILU Team

- Day-of-Launch DOLILU operations:
  - Prime
    - Generate DOL I-Loads
      - I-Loads = table of roll/pitch/yaw/throttle vs. altitude from launch pad, tailored for the launch day winds/atmosphere
      - Transfer I-Loads to KSC for upload to the vehicle
    - Perform trajectory assessment to verify that the I-Loads are safe to fly.
      - 6-DOF trajectory simulation flown with DOL winds/atmosphere/I-Loads
      - Trajectory run-through checker tools – one for Load constraints and one for Trajectory constraints
        - The constraints include a wind persistence component to account for wind change from the time the I-Loads are designed to when they could be flown.
        - Constraints must be met in order for DOLILU to be "Go" for launch
    - Compare results of prime and IV&V assessments to ensure similar results
    - LDO (Lead DOLILU Officer) provides "Go/No-Go" call on voice loop for integrated DOLILU team
  - Verification and Validation (V&V)
    - Perform wind and atmosphere V&V

MSFC DOLILU Team Function

SLS Natural Environments & Mission Analysis (NEMA) Team

- Natural Environments
  - Splices data from wind sources (TDRWP, LR balloons, Earth-GRAM monthly mean profiles).
    - Tropospheric Doppler Radar Wind Profiler (TDRWP) –wind data
    - Automated Meteorological Processing System (AMPS) Low Resolution Flight Element (LRFE) Balloons – wind and atmosphere data
    - A vertically-complete wind profile was generated by splicing data from the live wind data sources:
      - Spliced low balloon (0-10kft) + TDRWP (~6kft – 63kft) + High LR (sfc – 70kft) + EarthGRAM 2010 monthly mean
      - Input into multiple DOLILU software tools
  - Review displays of atmospheric data received from the Eastern Range and visually compare wind sources and cycle profiles.

- Mission Analysis
  - GNC Trajectory
    - Independent SLS Pre-Launch Check of Trajectories
      - Inputs trajectory and other inputs to provide an output report with 2-D trajectory performance plots and a go/no-go advisory table
      - Independent check on FOD trajectory constraint check tool
  - LDI Day-of-Launch Vehicle Load Indicator
    - Algorithm that determines internal loading of the vehicle, computes load indicators, and compares the load indicators to the vehicle limit loads that have been computed prior to the DOL
    - Independent check to verify FOD vehicle load indicator algorithm

Artemis I DOLILU Timeline

- To support the Artemis I launch, the DOLILU process involved several activities executed in Cycles:
  - Obtain DOL-measured wind/atmosphere data
  - Generate DOL I-Loads [Design cycle]
  - Verify DOL I-Loads [Assess cycle]
  - Upload I-Loads to SLS Flight Computer and verify the Upload [Upload cycle]
- In order to orchestrate the DOLILU process amongst DOLILU participants and stakeholders, a DOLILU Timeline was used.
  - The Timeline structure was fixed and anchored to the planned Launch Window Open time, which was unique for each launch day opportunity.
- The Timeline included multiple Cycles of activities.
  - Starting with an L-1 day checkout Design Cycle.
  - Then on DOL, two design cycles were conducted where I-loads were designed and assessed prior to Upload to the vehicle.
  - Because Artemis I had a variable launch window duration (based on launch day), the DOLILU Timeline included Assess cycles to continue checking the Uploaded I-Loads through the maximum possible launch window duration.
    - Maintained continuous planned launch window operational coverage.
    - Tied to the Wind Persistence duration built into the assessment constraints.

Artemis I DOLILU Timeline (cont'd)

- The DOLILU Timeline also specified the timing for the live ER weather assets used to measure atmospheric conditions and winds aloft.
  - Because the TDRWP data did not cover the entire altitude region as needed for the trajectory constraint verification, low and high LRFE balloon data were also used.
  - Raw wind data were processed at the CCSFS prior to delivery to JSC and MSFC.

- A DOLILU balloon schedule was generated to specify the timing for the balloon and TDRWP assets as outlined in the daily DOLILU Timeline.
  - Contained L-x and UTC times (therefore, a unique balloon schedule was available for each launch day opportunity).
  - A group of balloon schedules were provided to the ER to cover a set of possible Launch Days.

Use of ER TDRWP & Live Balloon Data: Sims

- Multiple development and training simulations ("sims") were conducted to incrementally exercise and test the DOLILU system in the years prior to launch.

- Worked through several issues during sims:
  1. Slow data transmissions over MIDDS (Nov 2019 sim) – became a DOLWG Action (Apr 2020)
     - RGNext worked the short term plan and tested a new modem, but did not have any success. The only way to get a faster circuit would be to submit a requirement statement to the ER and fund it.
     - DOLILU Team saw no further issues with this and have not requested any further formal action.
  2. Timestamp issues with the TDRWP when daylight savings started (system still recognizes "old" time change schedule; not an issue in the fall)
  3. AMPS A went down during first Wet Dress Rehearsal attempt; came back up as PMC but used AMPS B for remainder of test.
     - Used AMPS B for a few sims/tests until it was checked and monitored for a bit before considering FMC
  4. Some file transfers from Cape Weather did not go through as planned; usually resolved quicky but some retransmissions affected the timeline.
  5. Some TDRWP QC flag exceedances, slower balloon rise-rates, and beam interference due to winds/weather in the area allowed the team to practice back-up scenarios for making wind-splicing decisions for each cycle.

Use of ER TDRWP & Live Balloon Data: DOL

- There were multiple Artemis I attempts before a successful launch on 16 November 2022. DOLILU completed an L-1 day check-out for each LP attempt.
  - Launch Date: 29 August 2022 (LP25) -- SCRUBBED
    - No issues; TDRWP was successfully transitioned into SLS Mode for LP25 L-1 day check-out assessment shortly after supporting launch activities for SpaceX and being in EVR Mode.
    - DOLILU assessed through final cycle before launch attempt was scrubbed.
  - Launch Date: 3 September 2022 (LP25) -- SCRUBBED
    - No issues; some QC flag checks around the top of the TDRWP but nothing of concern and it was resolved with the wind splicing process.
    - Completed one DOL cycle before launch was scrubbed.
  - 16 November 2022 (LP28) -- LAUNCHED
    - L-1 day check-out showed some noise and QC checks in upper part of TDRWP.
      - Cape Winds saw no particular issues with the instrumentation.
      - There were several profiles that violated the QC checks.
      - A good profile was able to be selected for the assessment.
    - No issues on DOL!
      - Had very good rise rates on the balloon (light winds; downrange drift was east and not far).

Lessons Learned & Forward Work

Lessons Learned

- Communication between DOLILU and ER was critical during the sims/launch.
  - Improved communication so known issues were being communicated and made it easier for DOLILU to look for them and decide on a course of action.
    - Know if instrumentation is down or not functioning for any reason.
    - If too many flagged profiles, use back-up balloon.
    - If files were not coming across, making sure we could try to resend them right away.
  - The DOLILU balloon schedules for the primary launch and backup dates were submitted to the Eastern Range (ER) as early as possible to ensure the range had them in-hand when working launch deconflictions.

Forward Work

- Need to monitor balloon supply for sim/launch support.
  - Consider reduction in the Rawinsondes balloon count and/or other methods for assessing DOL weather needs.

- Need to complete several DOLILU software updates before Artemis II.

Summary

- The DOLILU Process was successfully implemented for the Artemis I Launch.
- The TDRWP and LRFE balloons were successfully used for day-of-launch winds assessments and fed into trajectory and loads analysis for go/no-go calls.
- DOLILU process will be updated for Artemis II, as needed, to incorporate any functions to support Orion abort wind analyses.
- There was a lot of value of the sims and practice ahead of time to implement this new approach for Artemis I – which was very different from Shuttle DOLILU.
- For Artemis I DOL, everything went smoothly and the process was well-choreographed by the team.

Great job by the DOL teams and special thanks to the CCSFS Cape Weather team for their support!